CLAIMS

What is claimed is:

1. High performance filter media comprising nanofibers of diameter less than 1 μm incorporated and processed into internal structure of a filter medium dominantly composed of coarse fibers of diameter greater than 1 μm.

2. The filter media according to claim 1 wherein said nanofibers and said coarse fibers are of different materials.

3. The filter media according to claim 1 wherein:

said nanofibers are selected from the group consisting of: polymeric materials; ceramic materials; acrylic; nylon; polyvinyl alcohol; polymeric halocarbon; polyester; polyaramid; polyphenylsulfide; cellulose; titania; glass; alumina; and silica; and

said coarse fibers are selected from the group consisting of: polymeric materials; ceramic materials; polyvinyl alcohol; cellulose; acrylic; polyester; polyaramid; titania; glass; silica; nylon; polyphenylsulfide; polymeric halocarbon; and alumina.

4. The filter media according to claim 1 wherein the ratio of coarse fiber diameter to nanofiber diameter is between 10 and 5,000.

5. The filter media according to claim 1 wherein said nanofiber diameter is less than 500 nm.

6. The filter media according to claim 1 wherein said nanofiber diameter is greater than 50 nm.

7. The filter media according to claim 1 wherein said nanofibers

comprise less than 5% by weight of the weight of said filter media.

8. The filter media according to claim 7 wherein said nanofibers comprise less than 1% by weight of the weight of said filter media.

9. The filter media according to claim 1 wherein said nanofibers are distributed uniformly throughout the filter media.

10. The filter media according to claim 1 wherein said nanofibers are distributed unevenly in the filter media such that said nanofibers are concentrated in bundles providing pockets of nanofibers in a matrix of coarse fibers, said pockets providing spatially distinct areas of greater filtration efficiency in a matrix of lesser filtration efficiency.

11. The filter media according to claim 10 wherein said nanofibers are provided in low enough concentration and small enough diameter that there is insubstantial difference in flow velocity, relative to media without nanofibers, through said media across a face thereof until said nanofiber bundles begin to plug, whereupon flow is increasingly diverted through coarse fiber sections in said matrix between said pockets such that filtration efficiency is increased relative to media without nanofibers at the same flow velocity and pressure drop, at least initially until said nanofiber bundles begin to plug.

12. The filter media according to claim 1 wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough, and wherein said nanofibers are concentrated at one of said faces and include a first set of nanofiber portions extending parallel to said one face, and a second set of nanofiber portions extending normal to said one face.

13. The filter media according to claim 1 wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough and defining a filter media thickness therebetween, and wherein:

said filter media has a macrostructure, defined as viewed at magnification of 5 to 50 X, selected from the group consisting of:

macrostructure A wherein said nanofibers are distributed uniformly throughout said filter media;

macrostructure B wherein said nanofibers are distributed unevenly in bundles providing pockets of nanofibers in a matrix of coarse fibers; and

macrostructure C wherein said nanofibers are concentrated at one of said faces;

and wherein said filter media has a nanofiber/coarse fiber interface providing a microstructure, defined as viewed at magnification of 50 to 500 X, selected from the group consisting of:

microstructure 1 wherein said nanofibers form bridges across pores between said coarse fibers;

microstructure 2 wherein said nanofibers substantially collapse onto said coarse fibers; and

microstructure 3 wherein there is no significant bridging of said nanofibers across said pores between said coarse fibers and no significant collapse of said nanofibers onto said coarse fibers, and instead said nanofibers clump together.

14. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure A and microstructure 1.

15. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure A and microstructure 2.

16. The filter media according to claim 13 wherein said filter media

is composed of the combination of macrostructure A and microstructure 3.

17. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure B and microstructure 1.

18. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure B and microstructure 2.

19. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure B and microstructure 3.

20. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure C and microstructure 1.

21. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure C and microstructure 2.

22. The filter media according to claim 13 wherein said filter media is composed of the combination of macrostructure C and microstructure 3.

23. The filter media according to claim 13 wherein said filter media is composed of macrostructure A, and wherein said nanofibers are distributed uniformly throughout said filter media in all three dimensions.

24. The filter media according to claim 13 wherein said filter media is composed of macrostructure B, and wherein each of said bundles comprises one or more nanofibers twisted and intermingled into an assemblage.

25. The filter media according to claim 24 wherein the longest

dimension of said bundle is less than said filter media thickness.

26. The filter media according to claim 25 wherein said longest dimension of said bundle is in the range of 10% to 50% of said filter media thickness.

27. The filter media according to claim 13 wherein said filter media is composed of macrostructure B, and wherein said bundles cumulatively occupy less than 20% of the volume of said filter media.

28. The filter media according to claim 13 wherein said filter media is composed of macrostructure C, and wherein said nanofibers are 3-dimensionally-randomly oriented at said one face such that some nanofiber portions extend parallel to said one face, and other nanofiber portions extend normal to said one face, such that the normally extending nanofiber portions increase attachment strength to said coarse fibers, reduce delamination risk of said nanofibers, and reduce pressure drop due to increased orientation of said nanofibers in the direction of flow.

29. The filter media according to claim 13 wherein said filter media is composed of microstructure 1, and wherein said nanofibers forming said bridges across said pores subdivide said pores into subpores having a size dependent upon the relative numbers of said nanofibers and coarse fibers.

30. The filter media according to claim 13 wherein said filter media is composed of microstructure 2, and wherein the interface of said nanofibers and said coarse fibers forms a composite fiber, with said nanofibers lying along and across said coarse fibers and creating channels for transport and drainage and providing an artificially roughened collection surface with increased surface area relative to coarse fibers alone.

31. The filter media according to claim 13 wherein said microstructure is selected from the group consisting of microstructure 1, microstructure 2 and microstructure 3, and wherein said nanofibers are selected from the group consisting of adsorptive materials and catalytic materials, to provide filter media of increased surface area for one of adsorptive and catalytic activity without substantially increasing restriction.

32. The filter media according to claim 13 wherein said microstructure is selected from the group consisting of microstructure 2 and microstructure 3 to bond said nanofibers to said coarse fibers and provide increased strength of said filter media and provide better retention of said nanofibers and of said coarse fibers.

33. The filter media according to claim 1 wherein said nanofibers have different triboelectric properties than said coarse fibers to provide a triboelectric effect for removing particles from a fluid to be filtered.

34. The filter media according to claim 33 wherein said nanofibers and said coarse fibers comprise first and second fiber types, respectively, and wherein:

one of said first and second fiber types is selected from the group consisting of: nylon, polyaramid; and cellulose; and

the other of said first and second fiber types is selected from the group consisting of: acrylic; polyester; polypropylene; and polymeric halocarbon.

35. The filter media according to claim 1 wherein said nanofibers have different adsorption properties than said coarse fibers.

36. The filter media according to claim 1 wherein said nanofibers have different surface charge characteristics than said coarse fibers.

37. The filter media according to claim 36 wherein said different surface charge characteristics provide a localized electric field gradient within said filter media enhancing particle removal from fluid to be filtered.

38. The filter media according to claim 1 wherein said nanofibers and coarse fibers have different wettability.

39. The filter media according to claim 38 wherein said filter media captures droplets from a liquid to be filtered, and wherein said nanofibers are preferentially wetted by said droplets, and said coarse fibers are preferentially non-wetted by said droplets, whereby to create a capillary pressure gradient wicking droplets off said coarse fibers, facilitating drainage.

40. The filter media according to claim 38 wherein said filter media captures and coalesces droplets from a liquid to be filtered, and wherein said nanofibers are preferentially non-wetted by said droplets, and said coarse fibers are preferentially wetted by said droplets, whereby to create a capillary pressure gradient wicking droplets off said nanofibers, facilitating coalescence and drainage.

41. The filter media according to claim 1 wherein said nanofibers are composed of material selected from the group consisting of catalytic materials, reactive materials, and adsorptive materials.

42. The filter media according to claim 1 comprising a trimodal distribution of fiber diameter comprising a first set of fibers in the diameter range 50 to 500 nm, a second set of fibers in the diameter range 1 to 5 μm, and a third set of

fibers in the diameter range 10 to 50 μm.

43. The filter media according to claim 42 wherein said first set of fibers is supported by said second set of fibers, and said second set of fibers is supported by said third set of fibers, said first set of fibers providing said nanofibers, said second and third sets of fibers providing said coarse fibers.

44. The filter media according to claim 43 wherein said first set of fibers form bridges across pores between said second set of fibers without substantial collapse onto said second set of fibers.

45. The filter media according to claim 44 wherein said second set of fibers comprise a fibrillated para-aramid polymer, and said third set of fibers comprise a cellulose matrix.

46. The filter media according to claim 1 wherein said nanofibers are flexible.

47. The filter media according to claim 1 wherein said nanofibers are of non-glass material.

48. The filter media according to claim 1 wherein said filter media filters a fluid selected from the group consisting of: gas, including air, exhaust, and crankcase ventilation gas; and liquid, including oil, fuel, coolant, water, and hydraulic fluid.

49. The filter media according to claim 1 wherein

said nanofibers are selected from the group consisting of: polymeric materials; ceramic materials; acrylic; nylon; polyvinyl alcohol; polymeric halocarbon;

polyester; polyaramid; polyphenylsulfide; cellulose; titania; glass; alumina; and silica; and

said coarse fibers are selected from the group consisting of: polymeric materials; ceramic materials; polyvinyl alcohol; cellulose; acrylic; polyester; polyaramid; titania; glass; silica; nylon; polyphenylsulfide; polymeric halocarbon; and alumina;

and wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough and defining a filter media thickness therebetween, and wherein:

said filter media has a macrostructure, defined as viewed at magnification of 5 to 50 X, selected from the group consisting of:

macrostructure A wherein said nanofibers are distributed uniformly throughout said filter media;

macrostructure B wherein said nanofibers are distributed unevenly in bundles providing pockets of nanofibers in a matrix of coarse fibers; and

macrostructure C wherein said nanofibers are concentrated at one of said faces;

and wherein said filter media has a nanofiber/coarse fiber interface providing a microstructure, defined as viewed at magnification of 50 to 500 X, selected from the group consisting of:

microstructure 1 wherein said nanofibers form bridges across pores between said coarse fibers;

microstructure 2 wherein said nanofibers substantially collapse onto said coarse fibers; and

microstructure 3 wherein there is no significant bridging of said nanofibers across said pores between said coarse fibers and no significant collapse of said nanofibers onto said coarse fibers, and instead said nanofibers clump together.

50. A method for manufacturing high performance filter media

comprising incorporating and processing nanofibers of diameter less than 1 μm into internal structure of a filter media dominantly composed of coarse fibers of diameter greater than 1 μm.

51. The method according to claim 50 comprising producing said filter media with a bi-component fiber process initially providing a precursor bi-component fiber which is reduced to a nanofiber upon removal of a carrier.

52. The method according to claim 51 wherein said precursor bi-component fiber process is selected from the group consisting of islands-in-the-sea and segmented-pie processes.

53. The method according to claim 52 comprising producing said filter media using said coarse fibers and said bi-component fibers, producing said bi-component fibers with said islands-in-the-sea process having a sea polymer as a carrier for an island polymer to provide said nanofibers upon removal of the sea polymer carrier, using a water soluble sea polymer and a water insoluble island polymer, using said water as a carrier to disperse and suspend said bi-component fibers and said coarse fibers to provide wet media and to provide a solvent for the sea polymer such that the water is the carrier for said bi-component fibers and said coarse fibers as well as the solvent for the sea polymer.

54. The method according to claim 53 comprising dissolving the sea polymer by heating the wet media.

55. The method according to claim 54 comprising performing said heating step as a separate hot rinsing step.

56. The method according to claim 54 comprising drying said wet

media, and performing said heating step by applying heat during said drying.

57. The method according to claim 54 comprising applying hot water to said media, removing said hot water by a step selected from the group consisting of vacuuming and draining, and applying heat to dry the media and using such applied heat as said heating step.

58. The method according to claim 54 comprising performing said heating step by increasing the temperature of said water and said media to dissolve said sea polymer, leaving said nanofibers behind and retained in said filter media.

59. The method according to claim 52 comprising producing said filter media with said islands-in-the-sea process having a sea polymer as said carrier, and dissolving said sea polymer with a solvent comprising phenolic resin.

60. The method according to claim 52 comprising producing said filter media with said islands-in-the-sea process having a sea polymer as said carrier, and dissolving said carrier with a solvent comprising a water-based resin.

61. The method according to claim 60 wherein said water-based resin system is selected from the group consisting of acrylic and water-based phenolic resin.

62. The method according to claim 60 comprising applying heat to cure said resin, and using said heat to facilitate dissolution of said sea polymer.

63. The method according to claim 50 comprising producing said filter media with a bi-component fiber process having a carrier and initially providing precursor bi-component fibers reduced to nanofibers upon removal of said carrier,

and comprising adding said precursor bi-component fibers to said coarse fibers prior to removal of said carrier.

64. The method according to claim 63 comprising dissolving said carrier with a solvent, and heating said solvent.

65. The method according to claim 63 wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough and defining a filter media thickness therebetween, and said filter media has a macrostructure C, defined as viewed at magnification of 5 to 50 X, wherein said nanofibers are concentrated at one of said faces, and comprising applying dispersed said precursor bi-component fibers across said one face.

66. The method according to claim 63 comprising separating said nanofibers formed by dissolution of said carrier from said precursor bi-component fibers by a step selected from the group consisting of: adjusting pH; adding dispersant; adding ions; altering wettability.

67. The method according to claim 63 wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough and defining a filter media thickness therebetween, and said filter media has a macrostructure C, defined as viewed by magnification of 5 to 50 X, wherein said nanofibers are concentrated at one of said faces, and comprising using said precursor bi-component fibers to create said macrostructure C.

68. The method according to claim 67 comprising using heat to remove said carrier.

69. The method according to claim 50 comprising producing said

filter media with a macrostructure A having said nanofibers distributed uniformly throughout said filter media.

70. The method according to claim 50 comprising producing said filter media with a macrostructure B having said nanofibers distributed unevenly in bundles providing pockets of nanofibers in a matrix of said coarse fibers.

71. The method according to claim 50 wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough and defining a filter media thickness therebetween, and comprising producing said filter media with a macrostructure C having said nanofibers concentrated at one of said faces.

72. The method according to claim 50 comprising producing said filter media with a microstructure 1 having said nanofibers forming bridges across pores between said coarse fibers.

73. The method according to claim 50 comprising producing said filter media with a microstructure 2 having said nanofibers substantially collapsed onto said coarse fibers.

74. The method according to claim 50 comprising producing said filter media with a microstructure 3 having no significant bridging of said nanofibers across pores between said coarse fibers, and no significant collapsing of said nanofibers onto said coarse fibers, and instead with clumping of said nanofibers together.

75. The method according to claim 51 comprising removing said carrier to yield bundles of nanofibers providing a macrostructure B having said

nanofibers distributed unevenly in said bundles providing pockets of nanofibers in a matrix of said coarse fibers.

76. The method according to claim 75 comprising reducing the length of said precursor bi-component fibers to a desired length providing shortened bi-component fibers, providing said shortened bi-component fibers as less than 5% by weight of the weight of said filter media, mixing said bi-component fibers with said coarse fibers to form a suspension in a dispersing fluid, removing said dispersing fluid, removing said carrier by a change in fluid temperature or by a solvent, before, during or after the step of removing the dispersing fluid, drying the media, and adding a binder or resin at a designated step as part of the dispersing fluid or separately following fluid or carrier removal.

77. The method according to claim 51 wherein said filter media has distally opposite upstream and downstream faces normal to flow therethrough and defining a filter media thickness therebetween, and comprising using said precursor bi-component fibers to produce filter media with a macrostructure C having said nanofibers concentrated at one of said faces.

78. The method according to claim 77 comprising reducing the length of said precursor bi-component fibers to a desired length providing shortened bi-component fibers, dispersing said shortened bi-component fibers in a fluid containing dispersants as needed to provide a bi-component fiber suspension, dispersing said coarse fibers in a fluid containing dispersants as needed to provide a coarse fiber suspension, removing the dispersing fluid from the coarse fiber suspension to provide a coarse fiber web, introducing the bi-component fiber suspension over the coarse fiber web at a time after the start of removal of the coarse fiber dispersing fluid, removing the dispersing fluid from the bi-component fiber suspension, removing said carrier by a change in fluid temperature or by a solvent,

before, during or after removal of the dispersing fluid for the bi-component fibers, drying the media, applying a binder or resin to the media at a designated step as part of the dispersing fluid or separately following fluid or carrier removal.